ON THE COSTS OF TUBERCULOSIS

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This paper is the result of studies made by the Metropolitan Life Insurance Company and the National Tuberculosis Association in order to shed additional light on the question of the economic cost of tuberculosis. Such investigation is a necessary part of the national anti-tuberculosis campaign. Public health work, as now practiced, is often expensive. In the effort to obtain the necessary appropriations with which to carry on their work, health officers are learning to utilize figures showing the economic loss sustained by preventable sickness and premature death in their respective communities. Facts of this kind carry much weight with hard-headed municipal authorities. Altogether, the program of health work is by this means put on a much safer footing. Such figures indicate the relative value of the several types of life conservation work when there is competition between them for public attention. Furthermore, they make it possible to show the character of the returns on the investment when work has been carried on for some time. The health officer who approaches his work from the point of view of the economic factors involved is more likely to keep his feet on the ground and to give a better accounting of his activities.

The first step in our method has consisted in preparing a series of life tables. These show on the one hand, the life expectation including all deaths and on the other, the expectation with tuberculosis excluded. The differences between the life expectation shown in these pairs of tables thus indicate the average number of years of life lost to each individual in a community because of the presence of tuberculosis; and conversely, the average number of years that would be added to the life span if we lived in an ideal community in which deaths from tuberculosis did not occur, and if other causes of death continued at prevailing rates. The method is not a new one. Professor Glover at the International Congress on Tuberculosis held in Washington in 1908 made such a presentation, but based it on the male population of the Registration States for the year 1900. Our purpose was to extend these observations to a later date and to include for comparison a group of insured persons among whom a fairly intensive campaign against tuberculosis had been made. Our material is based accordingly

upon the experience of the millions of insured wage-earners in the Industrial Department of the Metropolitan Life Insurance Company for a period of six years, 1911–16, and upon the facts for the total population of the Registration States as constituted in 1910. This area comprised 21 states and a little over half the population of the entire country. In the insurance experience it was possible to make distinction between the color and sex of the policyholders. In the general population this could not be done and it was necessary, therefore, to limit the study to the population as a whole without finer distinction. The two sets of findings serve as supplements to one another and, as we shall see, confirm in the main the accuracy of the methods* employed and of the results obtained.

The following table shows for each fifth year of age, beginning with age 0 for the group of wage-earners and with age 20 for the general population, the average after-lifetime, both when tuberculosis is present and when it has been completely eliminated as a cause of death.

TABLE I

AVERAGE AFTER-LIFETIME OF SPECIFIED POPULATIONS, WITH AND WITHOUT TUBERCULOSIS—ALL FORMS. BY COLOR AND BY SEX FOR INSURED WAGE-EARNERS, 1911–16 AND FOR TOTAL POPULATION OF REGISTRATION STATES, 1910

Age	Metropolitan Life Ins. Co., industrial policyholders, 1911–16								Population, registration states, 1910	
	White				Colored					
	Males		Females		Males		Females			
	Tbc. present	Tbc. absent	Tbc. present	Tbc. absent	Tbc. present	Tbc. absent	Tbc. present	Tbc. absent	Tbc. present	Tbc. absent
0	46.0	49.5	51.8	54.4	37.2	42.2	38.6	43.7	†	†
5	50.3	54.1	55.2	58.0	45.0	50.6	46.1	51.6	†	†
10	46.1	50.0	51.1	53.8	41.1	46.5	42.4	47.7	†	†
15	41.7	45.5	46.7	49.3	37.1	42.2	38.6	43.3	†	†
20	37.4	41.1	42.5	44.8	33.8	38.2	35.7	39.4	44.2	46.6
25	33.5	36.8	38.5	40.4	30.8	34.4	32.9	35.5	40.3	42.3
30	29.8	32.6	34.7	36.1	27.7	30.6	29.8	31.7	36.5	38.1
35	26.4	28.6	31.0	32.0	24.9	27.1	26.7	28.0	32.7	33.9
40	23.2	24.9	27.3	28.0	21.9	23.6	23.6	24.5	28.9	29.9
45	20.1	21.3	23.5	24.0	19.1	20.3	20.6	21.2	25.2	26.0
50	17.2	18.0	19.9	20.3	16.4	17.2	17.7	18.1	21.6	22.1
55	14.4	14.9	16.4	16.7	13.8	14.4	14.9	15.2	18.1	18.5
60	11.7	12.0	13.3	13.5	11.4	11.8	12.3	12.5	14.9	15.2
65	9.3	9.5	10.6	10.7	9.5	9.7	10.1	10.2	11.9	12.1
70	7.3	7.4	8.4	8.5	7.7	7.9	8.0	8.1	9.4	9.5
75	5.7	5.8	6.7	6.7	6.4	6.5	6.3	6.4	7.1	7.2
80	4.6	4.6	5.1	5.1	5.4	5.5	5.3	5.3	5.3	5.4
85	3.6	3.6	4.0	4.0	4.5	4.5	4.5	4.5	4.0	4.0
90	2.9	2.9	3.0	3.0	4.0	4.0	4.1	4.1	2.9	2.9
95	2.4	2.4	2.4	2.4	3.1	3.1	3.2	3.2	1.9	1.9

The loss of expectation of life due to tuberculosis is the difference between the corresponding figures in Table I at each age and is shown in the following table:

* A statement of the methods employed is presented in the Appendix, pp. 66.

† Data not computed.

TABLE II

LOSS IN YEARS OF AVERAGE AFTER-LIFETIME DUE TO TUBERCULOSIS—ALL FORMS

Age	Metropolitan Life Ins. Co., industrial policyholders, 1911–16				Population, registration states, 1910
	White		Colored		
	Males	Females	Males	Females	
0	3.5	2.6	5.0	5.1	*
5	3.8	2.8	5.6	5.5	*
10	3.9	2.7	5.4	5.3	*
15	3.8	2.6	5.1	4.7	*
20	3.7	2.3	4.4	3.7	2.4
25	3.3	1.9	3.6	2.6	2.0
30	2.8	1.4	2.9	1.9	1.6
35	2.2	1.0	2.2	1.3	1.2
40	1.7	.7	1.7	.9	1.0
45	1.2	.5	1.2	.6	.8
50	.8	.4	.8	.4	.5
55	.5	.3	.6	.3	.4
60	.3	.2	.4	.2	.3
65	.2	.1	.2	.1	.2
70	.1	.1	.2	.1	.1
75	.1	..	.1	.1	.1
80	..	..	.1	..	.1
85	..	..	..	..	..
90	..	..	..	..	..
95	..	..	..	..	..

The importance of the disease is indicated by the extent to which it shortens the average span of human life. Among insured wage-earners tuberculosis is a very powerful anti-longevity force. White males lose 3.5 years in all, or 7.6 per cent of their entire expectancy; white females, 2.6 years or 5 per cent of their expectancy. The heaviest losses occur among the colored people. Colored males and females lose an average of about 5 years of life because of the inroads of this disease, or 12.0 and 13.2 per cent, respectively. On the whole, males lose more heavily than females from tuberculosis. The slightly greater loss among colored females at age 0 is due to the high tuberculosis death rates prevalent among them under age 5; later in life the colored males show much greater losses than do colored females.

There is a gradual decrease with advancing age in the number of years of life lost on account of tuberculosis. Thus at age 20, when productive life is well started for most people, tuberculosis reduces the expectancy 3.7 years among white males, 2.3 years among white females, 4.4 years among colored males, and 3.7 years among colored females. At age 40, the years lost are from one-third to one-half as many as at age 20, and at age 60 and thereafter the losses cease to have an important effect upon longevity although the death rates from tuberculosis continue to be high, even at these advanced ages.

The loss in years of life is obviously greater among insured wage-earners than among the general population because tuberculosis death

* Data not computed.

rates are uniformly higher among the industrial groups. But even in the general population the loss in years is 2.4 at age 20, 1 at age 40, and 0.3 of a year at age 60.

The extent of the damage from tuberculosis appears to be closely associated with the life expectancy of the population in question whether we consider tuberculosis as a factor in mortality or entirely eliminate it. The loss from tuberculosis is high where longevity is low and is low where longevity is high. Thus at age 0, tuberculosis decreases the span of life 3.5 years for insured white males, but only 2.6 years among the longer lived white females, and about 5 years among the much shorter lived colored policyholders. The coefficient of correlation between longevity and the loss of longevity due to tuberculosis, based upon one hundred observations among insured wage-earners, is 0.791 ± 0.076.

TABLE III

TABLE FOR 100 OBSERVATIONS* AMONG INSURED WAGE-EARNERS, 1911–16, OF THE METROPOLITAN LIFE INSURANCE COMPANY, SHOWING CORRELATION BETWEEN LONGEVITY AND LOSS IN LONGEVITY FROM TUBERCULOSIS

		Longevity		Totals
		Low	High	
Loss in Longevity	High	a 43.5	b 7	a+b 50.5
	Low	c 15.5	d 34	c+d 49.5
	Totals	a+c 59	b+d 41	N 100

This suggests that the conditions of constitution and environment which determine the mortality from tuberculosis also in a measure determine the death rates from other important causes. Another possibility which must be considered is that the amount of mortality from tuberculosis may be determined by the prevalence of certain diseases which like typhoid fever, malaria, hookworm, and syphilis, undermine resistance; and that, conversely, tuberculosis, when prevalent, helps to impair physical vigor and thus increases the death rate from the so-called "degenerative diseases," such as heart disease, Bright's disease, and arteriosclerosis. All three factors are probably at work in different degrees in different communities. Tuberculosis

* The 100 Observations consisted of 25 random ages for the series White Male, White Female, Colored Male, and Colored Female. The dividing lines between high and low for any series were furnished by the average longevity and the average loss in longevity from tuberculosis respectively, for that particular series.

does not stand isolated but is closely bound up with environmental conditions on the one end and constitutional factors on the other, being determined by and determining the rate of loss from other diseases. This question is being attacked by means of a study of the losses of longevity from other important causes and will be reported upon at a later date.

Our next step was to express the losses in expectation described above in terms of estimated money losses. The importance of tuberculosis as a factor in national economy is in this way brought home more sharply. After an examination of the available data on wealth, income, and production in the United States, we concluded that a loss of one year of life was equivalent to a money loss of not less than $100 in national wealth. This conclusion was submitted to a group of economists who have busied themselves with such questions and they confirmed this estimate as in accordance with the best data available. We may say, therefore, that each year of life expectancy lost from tuberculosis by the population of the United States represents a loss of $100 in national wealth. In view of the fact that tuberculosis mortality cuts approximately two and one-half years from the complete life expectation of every individual under present mortality conditions, the loss per person is at least $250. This, in a population of approximately one hundred and six millions, represents a loss of twenty-six and a half billions of dollars. The present generation would add that much more net wealth if tuberculosis were not a factor in mortality. Since the average lifetime is approximately fifty years in the United States, this loss means an annual charge in excess of five hundred million dollars from the curtailed longevity of individuals because of tuberculosis.

No consideration has as yet been given to the very large additional losses which result from the long periods of sickness due to tuberculosis. The losses from disability for work, the cost of medical, nursing, and extra dietary and other care, add very materially to the figures quoted above. It is not possible for us at this time to offer even an estimate of this loss. The amount is enormous. One of us in a study of the records of the Association for Improving the Condition of the Poor (New York City), which has for a number of years conducted intensive relief measures for the care of tuberculous families, found that a tuberculous family was under care, on the average, for a period of two years, four and one-half months, and that during this time the families suffered a wage loss of $836 and the Association contributed $1,181 in relief and care. These data are not sufficient in themselves to determine the community loss in tuberculous families, but they suggest how much

the items will be when more extensive and more detailed information becomes available.

Our study has shown the important part that tuberculosis plays as a factor in modern economic life. The amount of damage done is great enough to justify large expenditures for the control of tuberculosis as a cause of sickness and death. The tuberculosis death rate has declined and is still declining. Among industrial policyholders of the Metropolitan Life Insurance Company the death rate has in recent years been reduced very rapidly. In this organization special efforts have been made to instruct the great body of policyholders in methods of preventing and combating the disease, apparently with good results. The death rate from tuberculosis of the lungs in the entire experience has declined 30.3 per cent between 1911 and 1919. During 1920, to date, the experience is reaching low figures previously thought to be unattainable. In fact, the tuberculosis death rate of insured wage-earners is now almost as low as in the general population, although ten years ago there was an excess of 41 per cent in the death rate among these people as compared with that of the general population. In view of the complexity of the problem it is not possible to measure with any exactness the direct relation between the various efforts expended and the results obtained by the anti-tuberculosis campaign. Yet the results are indicative that the work has borne fruit. These achievements clearly call for a continuance of the anti-tuberculosis program along the lines now being followed.

Appendix

Method of constructing and graduating the insurance* tables

Method of construction

The number of lives exposed to risk, the number of deaths from all causes and from all forms of tuberculosis, were obtained from the public health statistical records of the Industrial Department for the years 1911 to 1916. A complete tabulation of the deaths according to color, sex, and age is shown in a publication by the Metropolitan Life Insurance Company, entitled "Mortality Statistics of Insured Wage-Earners and Their Families." In these tables, age distinctions are shown by single ages under 5 years and by 5-year groupings up to the group "75 years and over." The data were graduated by interpolation formulae and these processes were applied to the exposures and to the deaths from all causes and from tuberculosis—all forms.

The pivotal values were obtained by means of Formula I. The q_x

* The mathematical work of this paper was carried out by Mr. Frank Langellotti, formerly of the Statistical Bureau of the Metropolitan Life Insurance Company.

values were computed by means of Formula II, formula (a) being used for all causes of death and (b) for tuberculosis. The differences were tabulated as far as and including the fifth difference and the intermediate q_x was derived by the osculatory interpolation Formula III. The q_x values beyond age 70 were obtained by Formula IV. (For tuberculosis beyond age 75, the insurance figures were adjusted in accordance with the general age trend of mortality from tuberculosis—all forms, in the data of the registration area of the United States.) For both, all causes of death and tuberculosis, the values for single ages, 0 to 1, were computed by Formula V. The q_x values for ages 2, 3, and 4 are ungraduated, while those for ages 5 and 6 were computed by Formula VI. Two life tables were constructed, the one based upon the q_x values for all causes of death and the other, upon q'_x in which the q'_xs for tuberculosis—all forms were eliminated.

The tetrachoric coefficient of correlation and its probable error were obtained by VII and VIII respectively.

Formulae

$$u_{x+7} = \cdot\ 2w_{x+5} - .008\Delta^2 w_x \qquad \text{(I)}$$

where

$$w_x = u_x + u_{x+1} + \ldots . + u_{x+4}$$

$$q_x = \frac{\theta_x}{L_x + \frac{1}{2}\theta_x} = \frac{\theta_x}{l_x} \qquad \text{(a)} \qquad \text{(II)}$$

$$q'_x = \frac{\theta'_x}{l_x} \qquad \text{(b)}$$

where θ_x represents deaths, L_x the mean population, both for age x to $x+1$; and the prime signifies tuberculosis.

$$u_{x+n'} = u_x + n\Delta u_x + \frac{n(n-1)}{2}(\delta^2 u_{x+5} - 1/6\delta^4 u_{x+5}) + \frac{n(n-1)(n-2)}{6}(\delta^3 u_{x+5/2} - 1/6\delta^5 u_{x+5/2}) \qquad \text{(III)}$$

where the δ's are central differences, n' is the interpolation interval, and n is n' divided by the tabular interval.

In terms of ordinary differences (III) becomes

$$u_{x+n'} = u_x + n\Delta u_x + \frac{n(n-1)}{2} \cdot (\Delta^2 u_x - 1/6\Delta^4 u_{x-5}) + \frac{n(n-1)(n-2)}{6} \cdot (\Delta^3 u_{x-5} - 1/6\Delta^5 u_{x-10}) \qquad \text{(III')}$$

$$\Delta q_{70+x} = \Delta q^{G}_{70+x} \cdot \frac{q^{G}_{105} - q_{70}}{q^{G}_{105} - q^{G}_{70}} \qquad \text{(IV)}$$

where G signifies Glover's City Table in case of white and Registration States Table in case of colored

$$\begin{aligned} q_{70+x} &= q_{70+(x-1)} + \Delta q_{70+(x-1)} \\ q_0 &= \frac{q_2}{q^{G}_{2}} \cdot q^{G}_{0} = k q^{G}_{0} \\ q_1 &= k q^{G}_{1} \end{aligned} \qquad \text{(V)}$$

where G means the same as in (IV)

Lagrange's formula:

$$\begin{aligned} q_x = q_a &\cdot \frac{(x-b)(x-c)\ \ldots\ (x-n)}{(a-b)(a-c)\ \ldots\ (a-n)} \\ + q_b &\cdot \frac{(x-a)(x-c)\ \ldots\ (x-n)}{(b-a)(b-c)\ \ldots\ (b-n)} \\ + &\ \ldots\ldots\ldots \end{aligned} \qquad \text{(VI)}$$

$$\left.\begin{aligned} r &= \sin\left(\frac{\pi}{2} \cdot \frac{1}{(1+K^2)^{\frac{1}{4}}}\right) \\ K^2 &= \frac{4\,abcdN^2}{(ad-bc)^2(a+d)(b+c)} \end{aligned}\right\} \qquad \text{(VII)}$$

$$pe_r = 3\left(.6745\frac{1-r^2}{\sqrt{n}}\right) \qquad \text{(VIII)}$$

I, II, III, and VI may be found in *Actuarial Studies No. 4*, published by the Actuarial Society of America; VII, in Davenport's *Statistical Methods;* and VIII, in Elderton's *Frequency Curves and Correlation.*

METHODS OF CONSTRUCTING AND GRADUATING THE REGISTRATION AREA TABLES

The methods of graduating the data for the population of the registration area of the United States were as follows. The mean population (L_x) at quinquennial intervals was computed by Formula I. The number of deaths, both from all causes and from all causes excepting tuberculosis—all forms, were similarly treated. The pivotal central death rates obtained by Formula IX were transformed into q_x values by means of Formula X. For the pivotal values of q_x

beyond age 87, a constant fourth difference was calculated from Formula XI and applied continuously to obtain the lower differences and finally the q_x values themselves. The intermediate q_x values were derived by means of the osculatory Formulae XII and XIII. The former was used for the age range, 22 to 82 years, and the latter for the portions from ages 17 to 22 and from 82 to 97 years. The q_x values at ages 98, 99 and 100 were derived by means of the constant third and fourth single-year differences from Formula XIV. From ages 5 to 17, the computations were obtained from Formula XV by applying the differences upwards.

Formulae

$$m_x = \frac{\theta_x}{L_x} \tag{IX}$$

$$q_x = \frac{2m_x}{2+m_x} \tag{X}$$

$$\Delta^4 q_{72} = \frac{1}{25.5024}(q_{105} - q_{72} - 6.6\Delta q_{72} - 18.48\Delta^2 q_{72} - 28.336\Delta^3 q_{72})$$

in which q_{105} is assumed to be unity (XI)

$$\begin{aligned}
\nabla u_{x+10} &= \left(\frac{\Delta}{5} + \frac{8}{5^2}\Delta^2 + \frac{11}{5^3}\Delta^3 - \frac{11}{5^4}\Delta^4 + \frac{\Delta^5}{5^4}\right)u_x \\
\nabla^2 u_{x+10} &= \left(\frac{\Delta^2}{5^2} + \frac{6}{5^3}\Delta^3 + \frac{\Delta^4}{5^4} + \frac{3}{5^4}\Delta^5\right)u_x \\
\nabla^3 u_{x+10} &= \left(\frac{\Delta^3}{5^3} + \frac{4}{5^4}\Delta^4 - \frac{3}{5^4}\Delta^5\right)u_x \\
\nabla^4 u_{x+10} &= \left(\frac{1}{5^4}\Delta^4 - \frac{2}{5^4}\Delta^5\right)u_x \\
\nabla^5 u_{x+10} &= \frac{1}{5^3}\Delta^5 u_x
\end{aligned} \tag{XII}$$

where ∇ signifies single-year differences

$$\begin{aligned}
\nabla u_{x+5} &= \left(\frac{1}{5}\Delta + \frac{3}{25}\Delta^2 - \frac{2}{125}\Delta^3\right)u_x \\
\nabla^2 u_{x+5} &= \left(\frac{1}{25}\Delta^2 - \frac{2}{125}\Delta^3\right)u_x \\
\nabla^3 u_{x+5} &= \frac{3}{125}\Delta^3 u_x
\end{aligned} \tag{XIII}$$

$$\nabla^3 q_{95} = \frac{1}{90}(6q_{102} - q_{105} - 5q_{95} - 32\nabla q_{95} - 81\nabla^2 q_{95})$$
$$\nabla^4 q_{95} = \frac{1}{35}(q_{102} - q_{95} - 7\nabla q_{95} - 21\nabla^2 q_{95} - 35\nabla^3 q_{95}) \qquad \text{(XIV)}$$

using this value as a constant

$$\nabla^2 q_{18} = \frac{1}{1365}(143q_{12} - 10q_5 - 133q_{18} - 728\nabla q_{18})$$
$$\nabla^3 q_{18} = \frac{1}{20}(q_{12} - q_{18} - 6\nabla q_{18} - 15\nabla^2 q18) \qquad \text{(XV)}$$

using this value as a constant.

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